SMITHSONIAN INSTITUTION
ASTROPHYSICAL OBSERVATORY

OPTICAL SATELLITE TRACKING PROGRAM

Carried out under Grant Number NsG 87

from the

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Semiannual Progress Report No. 12

January 1 through June 30, 1965

Project Director: Fred L. Whipple

CAMBRIDGE, MASSACHUSETTS 02138

SMITHSONIAN INSTITUTION
ASTROPHYSICAL OBSERVATORY

OPTICAL SATELLITE TRACKING PROGRAM

Carried out under Grant Number NsG 87

from the

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Semiannual Progress Report No. 12

January 1 through June 30, 1965

Project Director: Fred L. Whipple

CAMBRIDGE, MASSACHUSETTS 02138

TABLE OF CONTENTS

HIGHLIGHTS

From an analysis of satellite drag data gathered between sunspot maximum (1958) and sunspot minimum (1964), new atmospheric models based on diffusion equilibrium have been derived. These models have been adopted by the U. S. Committee on the Extension of the Standard Atmosphere.

A seasonal effect existing at middle and high latitudes at all atmospheric heights up to at least 600 km has been discovered.

With zonal harmonics through J_{14} as known quantities, more than 26,000 observations of 11 satellites were used to compute a new set of tesseral harmonics through the sixth degree.

A procedure has been developed to combine the results of the intervisible (geometric) and the orbital (dynamic) methods to determine still more accurate station coordinates and tesseral harmonics through the fourth order. It is gratifying that the two methods are in good agreement.

The Computations Division is developing programs that analyze the accumulated simultaneous observations and the interstation visibility patterns.

The network of astrophysical observing stations made 29,980 successful satellite observations from 68,043 predictions of transits supplied by headquarters in Cambridge.

On June 30 the station in New Mexico photographed for the first time Satellite S-66 by means of a pulsed ruby laser. The return from the satellite was recorded simultaneously by the Baker-Nunn camera and by a laser photometer.

More than 18,000 satellite positions were determined with corresponding times on the system A.1.; approximately 7,300 of these were of simultaneous observations.

DATA ACQUISITION

SATELLITE TRACKING AND DATA ACQUISITION DEPARTMENT

In April the Station Operations Division was reorganized as the Satellite Tracking and Data Acquisition Department under the direction of Mr. John Hsia. This reorganization will help the operations group to cope effectively with an increasingly large, complex and geographically dispersed Satellite Tracking Program by decentralizing decision-making authority and creating well-defined channels of communication among the elements of the Department.

During the period of this report, the Department continued to track satellites, both on assignment by the National Aeronautics and Space Administration, and to meet the special requirements of Observatory scientists engaged in research programs. From 68,043 predictions sent to the Baker-Nunn stations, 28,980 successful observations resulted (see Tables 1 and 2). These figures represent an increase of 37% in predictions and 32% in observations over the same period in 1964.

Predictions for simultaneous observations were greatly increased. Up to March 15, we obtained 1161 successful two-station photographs, 172 three-station photographs and 7 four-station photographs, bringing the totals to date in each of these categories to 3572, 412 and 8, respectively. In order to derive the maximum benefit from our network of camera stations, we have through an arrangement with NASA, continued cooperative observing under agreements with various agencies of the Department of Defense, including the U.S. Air Force, and we concluded an informal agreement with the Royal Radar Establishment of Malvern, England, for use of one of their Schmidt cameras. Stations of the SAO net made simultaneous observations with the USAF stations on Johnston Island, at Cold Lake, Alberta, Canada, at Oslo, Norway, and on Kwajalein Atoll. At various times SAO observers were at each of these stations assisting personnel in conducting observations and recording data.

On June 20, the S-66 satellite was successfully photographed for the first time by the New Mexico camera, using the reflected light of a pulsed ruby laser. The return from the satellite was recorded simultaneously by the Baker-Nunn camera and a laser photometer. This technique gives promise of providing improved range measurements of orbiting satellites.

Plans to relocate the Iranian station in Ethiopia continued to develop. We began planning for the removal of the Villa Dolores station in Argentina to the vicinity of Comodoro Rivadavia, and the transfer of the Curaçao station to the eastern tip of Brazil.

Equipment and Instrumentation

Baker-Nunn camera optics and mechanics -- Mechanical engineering representatives inspected and repaired the cameras in Florida and New Mexico. A repolished corrector cell, fitted with a protective window, was installed at the Florida station. A rebuilt primary-drive transmission was installed in Florida to replace a defective unit. Experimental models of a track-angle slew device and double azimuth clamps were installed on the Florida camera; further development work is required before units can be manufactured for other stations.

TABLE 1

COMPARISON OF OPERATIONAL RESULTS

January-June 1964-1965

Number of Predictions

Month	1964	1965
January	8819	9879
February	7975	10395
March	8032	10662
April	8587	11678
May	8748	13155
June	7570	12274
Total...	49731	68043

Increase in number of predictions. 37%

Number of Successful Observations

Month	1964	1965
January	3313	3666
February	3528	4716
March	3088	4550
April	3668	5035
May	4314	5518
June	4025	5495*
Total...	21936	28980

Increase in number of observations. 32%

Monthly Station Averages

Average/ month/ station	1964	1965
Predictions	691	945
Observations	305	403

*Estimated June 1965 observations

TABLE 2

SUCCESSFUL OBSERVATIONS BY INDIVIDUAL TRACKING STATIONS

January-June 1964-1965

Station		Number of Successful Observations*	
		1964	1965
New Mexico (SC-1)		2670	2946
South Africa (SC-2)		2233	2666
Spain (SC-4)		1883	2215
Japan (SC-5)		765	1234
India (SC-6)		2470	3470
Peru (SC-7)		1304	1517
Iran (SC-8)		1622	2732
Curaçao (SC-9)		1479	2225
Florida (SC-10)		1493	2405
Argentina (SC-11)		1832	2259
Hawaii (SC-12)		1536	2282
Australia (SC-23)		2649	3029
	Total...	21936	28980

*Estimated June 1965 observations

Extensive focus tests were made at the New Mexico station to determine an improved figure for the film backup plate.

Mechanical engineering representatives visited the Baker-Nunn camera station of the MIT Lincoln Laboratories on Kwajalein Island, to design a chopping shutter for the camera suitable for satellite photography. A shutter was manufactured and installed.

Norrman Timing Systems -- Routine operation and maintenance of the Norrman Timing Systems have continued at all stations.

Precision Timing Systems -- Acceptance tests have been conducted on seven of the 12 production models of the Precision Timing Systems. Five of these have been shipped, and units are in operation in Florida and New Mexico.

Training sessions in the operation, maintenance and repair of the new systems were conducted at the manufacturer's facility in Santa Ana, California; observers from New Mexico, South Africa, Australia, Spain, India, Iran, Peru, Curaçao, Florida, Argentina and Hawaii Baker-Nunn stations attended.

Film -- We have continued the evaluation of Extended-Red Royal-X Pan Recording (Kodak 2475) film for satellite photography, conducting specific comparative limiting-magnitude tests and other field tests.

Station vehicles -- Normal operation and maintenance of vehicles have continued.

The Florida station took delivery of a 1965 Chevrolet Carry-all in March, and a requisition is currently being processed to furnish a new Land Rover for the Iranian station.

Observer Training Program

During the period of this report we trained four new observers. At the end of June, two others were in training and several more were scheduled to begin training soon. During the period we also organized several brief familiarization sessions for experienced SAO observers and for guests of the Observatory.

In recognition of the advantages which accrue to Americans who have a working knowledge of the language of the host country, the language training program has been continued at the Peru and Argentine stations and, because of its function as a training center, at the New Mexico station.

Finally, the feasibility of using programmed material for observer training is being studied.

Moonwatch

There are now 122 active Moonwatch teams with permanent sites, and some half-dozen others engaged only in re-entry patrol activities. Two new teams in New Zealand and one in Switzerland have reported observations.

In the past six months 4080 observations have been reported.

One re-entry was observed by three Moonwatch teams in Europe. Attempts to observe the re-entry of 23 other satellites were unsuccessful.

The Low-Perigee Program is proceeding satisfactorily, and the number of teams capable of sufficiently accurate observations to be included has risen from 16 to 25.

Special efforts are being made to observe satellites of high inclination in the parts of their orbits not accessible to Baker-Nunn cameras.

In April, Albert Werner joined headquarters staff as Assistant Chief of Moonwatch.

During this period, four U.S. Moonwatch teams were visited by headquarters personnel.

Future Plans

We plan to continue the acceptance and installation of Precision Timing Systems at all stations.

We plan to install a refurbished optical system, with protective window, at one station, and to realuminize mirrors at two stations.

In addition to the repairs and modifications to equipment which are implied by the station relocations mentioned, we plan to build and deploy several geodetic tracking cameras, some of them to the former sites of Baker-Nunn cameras. In this connection we have made design modifications in the U.S. Air Force K-50 aerial reconnaissance camera to adapt it to satellite tracking. Tests of a prototype modified K-50 are under way at the Agassiz station of the Harvard College Observatory in Harvard, Massachusetts.

COMMUNICATIONS

During January a teletype circuit was established with the First Naval District Communications Center (COMONE) in Boston. The circuit has proved valuable as an alternate route for passing satellite-tracking data to and from our Baker-Nunn stations in Hawaii, Japan and Spain and other interested agencies during outages on our regular military link. Through a reciprocal agreement with COMONE we also serve as their alternate route in the event that they have an outage on their circuit.

The teletype relay distribution list for long satellite bulletins was carefully culled during this report period, and eight addressees were deleted and placed on a mailing list. Many hours of valuable circuit time are thus being saved and circuits kept open for higher-priority traffic.

On June 10 SAO Communications participated in an "overseas communications demonstration" for Western Union International, Inc., whereby we were placed in direct contact, by Telex, with observatories at Jodrell Bank, England, and Meudon, France, via the Early Bird satellite. One message pertaining to flare stars and another to tracking of the S-66 satellite were transmitted to Jodrell and Meudon, respectively. This demonstration represents a new step forward in message and data communications and could prove valuable to the Satellite Tracking Communications program in the future.

For the six-month period of this report, the communications center handled an average of approximately five million words per month to a general increase in all types of message traffic and, more specifically, an increase in our satellite predictions for simultaneous observations in connection with our geodetic program.

DATA PROCESSING

DATA DIVISION

This Division computes predictions of satellite positions for the various satellite-tracking stations; derives orbits from observations made by Baker-Nunn, Moonwatch or other tracking systems; prepares smoothed and mean orbits (from both field-reduced and photoreduced data) for publication in SAO Special Reports; records information that may affect research on satellite orbital data; publishes predictions, orbital elements and equator crossings; and handles the routine technical correspondence of the Satellite Tracking Program.

Two-hundred and fifteen nominal and revised early-tracking predictions for the Baker-Nunn cameras were derived for the nine NASA launches made during this period.

We processed Baker-Nunn, Moonwatch and other observations, and derived orbits each week by means of the Differential Orbit Improvement Program. Employing SCROGE, Ephemeris II, Ephemeris IV and Ephemeris VI programs, we used these orbits to produce predictions for the Baker-Nunn stations and selected Moonwatch sites.

Mean and smoothed orbital elements were derived and published for the satellites listed in Table 3. We also published observations of the satellites listed in Table 4.

The network regularly tracked as many as 32 satellites, and tracked other objects for launch backup and special purposes.

Special predictions on BE-B, BE-C, and Echo I and II were prepared for the Smithsonian/ General Electric cooperative laser project. Other predictions were made to test the Prairie Network cameras.

We also prepared for requesting agencies special predictions for objects of particular interest, including Explorer 19, Pegasus A, Echo I, Echo II and the other balloon satellites. The predictions usually took the form of look-angles. Among the recipients were U.S. Coast and Geodetic Survey, Raytheon Company, Bell Telephone Laboratory, Royal Radar Establishment, Langley Research Center, Aero-Space Corp., Northrop Nortronics, and The Marshall Space Flight Center. Public information predictions on bright objects for the Boston, New York, and Washington areas were also made.

A merge-and-sort computer program was devised and is currently being programmed to remove conflicts between simultaneous and regular satellite predictions. A program to compute incoming statistics on both simultaneous and regular observations was also started. The simultaneous observing project began using two completed computer programs, Detsin for checking simultaneity, and a histogram program showing distribution of plane of intersection. A conversion program was completed to accept Norad radar observations during this period. Ephemeris Zero was modified to give sub-satellite track data within specified latitude as well as time limits. A comet prediction program was completed and checked against past results.

TABLE 3

ORBITAL ELEMENTS

Satellite	Special Report Number
1958 Alpha (Explorer I)	169
1959 Alpha 1 (Vanguard II)	169
1959 Eta (Vanguard III)	169
1960 Xi 1 (Explorer VIII)	169
1961 Delta 1 (Explorer IX)	169
1960 Iota 1 (Echo I)	169
1962 Alpha Epsilon 1 (Telstar I)	169
1962 Beta Mu 1 (Anna 1B)	169
1962 Beta Tau 2 (Injun III)	169
1962 Beta Upsilon 1 (Relay I)	169
1963 13A (Telstar II)	169
1963 26A (Geophysical Research)	169
1963 30D	169

TABLE 4

OBSERVATIONS

Satellite	Special Report Number
1958 Alpha (Explorer I)	177
1959 Alpha 1 (Vanguard II)	177
1959 Eta (Vanguard III)	177
1960 Iota 1 (Echo I)	177
1960 Iota 2 (Echo I Rocket)	177
1960 Xi 1 (Explorer VIII)	178
1961 Delta 1 (Explorer IX)	178
1961 Omicron 1 (Transit 4A)	178
1961 Omicron 2 (Injun-Solar Radiation 3)	178
1962 Omicron 1 (S51/UK1)	178
1962 Alpha Epsilon 1 (Telstar I)	178
1962 Alpha Xi 1 (Cosmos VIII)	178
1962 Beta Tau 2 (Injun III)	179
1962 Beta Mu 1 (Anna 1B)	179
1962 Beta Upsilon 1 (Relay I)	179
1962 Beta Alpha 1 (Alouette)	178
1963 9A (Explorer XVII)	179
1963 10A (Cosmos XIV)	179
1963 13A (Telstar II)	179
1963 26A (Geophysical Research)	179
1963 30D	179

Several lists of satellite characteristics were compiled, and work was completed on a 400-entry bibliography on satellite geodesy for publication. Data for several subsequent publications were compiled preliminarily.

Star Catalog Tapes and Cards

Twenty-two copies of the SAO Star Catalog (FK-4 system) have been sold. The tape library is checked periodically and preventive tape copying is continually performed.

Several additional tapes related to the star chart project were generated. Program decks for the approximately 200 star catalog programs have been cataloged and filed.

The NGC and IC (catalogs of nonstellar objects) were put on tape and their positions precessed to 1950.0. They are to be included in the plotted star charts.

Some small catalogs were used by the keypunchers as fill-ins and were punched and loaded on tape.

Star Charts

The programs to produce the SAO Star Charts were completed during this period and are being run to produce punched cards for the EAI Dataplotter. The next phase of the project, consisting of plotting the charts at a double scale and inking all images with a specially made drafting template, was begun. Seven summer draftsmen and two plotter operators were hired to complete this phase of the project.

Printed Catalog

The second complete run of the star catalog from magnetic tapes via CRT to film-positives was successfully completed. Plates for printing are subsequently to be made from the film.

Bibliography of Catalogs

The exhaustive investigation of star catalogs for systems and accuracies continued.

PHOTOREDUCTION DIVISION

In this period the Division determined 18,338 satellite positions with corresponding times on the system A.1. This figure is roughly equivalent to that for the previous period. However, it should be noted that resources devoted to other grants and contracts increased sharply. Nearly 1/6th of our total effort was expended on projects not involved with the tracking of satellites, such as Celescope, comet tail angle study, comet magnitude study, etc.

The number of films received and cataloged by the Division's Film Control Section amounted to 28,783.

The Simultaneous Observing Program constituted a large portion of our work this period. Included in the total output figure mentioned above were roughly 7300 simultaneous observations.

Special Projects

Mr. I. G. Campbell, Division Technical Officer, conducted an analysis of a number of films taken with the Baker-Nunn camera on Kwajalein Island. He determined that results from this camera (which differs from a standard Baker-Nunn in that it employs fiber elements in its optical system) would be less accurate by a factor of ten than those obtained from a typical SAO camera.

In cooperation with the Commerce Department's Coast and Geodetic Survey, we completed the precise reduction of a series of photographs of the Echo I satellite that were obtained from the Baker-Nunn station in Cold Lake, Alberta, Canada. The films were known to be simultaneous with photographs made by a Coast and Geodetic Survey geodetic station network located in the Cold Lake area of western Canada.

In the cooperative program with the Royal Radar Establishment, Photoreduction will reduce satellite photographs obtained with one of the Schmidt cameras located near Malvern. These photographs will be simultaneous with those from other camera stations participating in this geodetic effort. Preliminary results indicate that we should obtain a significant amount of precise data from these plates.

In June, Richard Poland and Albert Marcella participated in observer training at the Jupiter, Florida, tracking station. This was the beginning of a program to familiarize key Photoreduction personnel with the equipment and operating procedures of the Baker-Nunn stations.

COMPUTATIONS DIVISION

The Computations Division is responsible for the development of computer programs for all phases of the satellite program, for the operation of existing computer programs and for development work in applied mathematics required to execute these objectives. The computer programs are run on the Harvard University IBM-7094.

Projects

Simultaneous observations -- The predicting and processing of simultaneous observations continue. We wrote and are developing programs that analyze the accumulated simultaneous observations and the interstation visibility patterns. We can then more intelligently make simultaneous predictions and combine them with our routine predictions. We are converting the ANNA flash observations to standard format. We modified GRNSMO, which determines time of simultaneity, to allow for diurnal aberration. The Köhnlein/Izsak program that corrects station positions and harmonics is being continually refined.

Planetary disturbing function -- The first-order analytical Planetary Perturbations Program is almost complete. There remains only a study of the limiting parameters for the infinite Fourier developments.

Geophysical calculations -- We have completed various models describing the heatflow of the earth and are recomputing the geopotential gradient using higher-order harmonics. We are modifying the tesseral harmonics program to allow us to recover from the machine failures that are unavoidable when processing large data sets.

Star catalogs and charts -- We completed a first draft of the printed star catalog on the SC-4020 and are refining it. We are writing programs that control the plotter in the preparation of star charts.

Systems programming-- Our major systems effort was directed toward integrating our new Control Data 3200 computer into our operation. The peripheral monitor system was successfully completed, and the 1401 simulator was adapted to our needs. SAMMY, the 7094 monitor system, was written to facilitate debugging 7094 programs on the 3200.

Doppler data -- We are writing new programs to allow us to add doppler information to our data base. These programs include a doppler ephemeris and modification of DOI to use range-rate observations.

Maintenance Status

The following programs are routinely used and maintained. Those starred are being rewritten in FORTRAN to minimize the difficulty in routinely tracking satellites while changing computers.

a) The Preparation Program
b) The Reduction Program
c) * DOI, the differential orbit improvement program
d) * SCROGE, the Baker-Nunn prediction program
e) Ephemerides 0, 6 and 7.

Publications

The Computations Division was involved in the following:

1. Simon, N.; SIMO, Simultaneous Observation Program; December 20, 1963.
2. Feit, B.; ERROR, Station Coordinate Correction Error Checking; May 1964.
3. Johnson, G.; THSTA, Tesseral Harmonics Program; June 1964.
4. Feit, B.; ROOTD, Root Finding Routine; June 16, 1964.
5. Kulvinskas, V.; MINDOI, Minitrack/ DOI Data Conversion; July 1964.
6. Gaposchkin, E.M.; DOI3.5, DOI Modifications; October 30, 1964.
7. Loeser, R.; GAUSS, Quadrature Routine; January 26, 1965.
8. Staff, NEWS 6, Programming News No. 6.
9. Joughin, W.; WRARA, General Array Printer in Terms of Magnitude Display; January 1, 1965.
10. Brown, S., Emerson, L, and Joughin, W.; Modifications to Eph 6 -- Shadow latitude determination, the Cospar and Cospar numbering conventions occur in printout; April 27, 1965.
11. Joughin, W.; SAGE, Modification on control and expansion 14th order zonal harmonics; January 1965.
12. Joughin, W.; Changes in SAMMY II Specs, Systems Memo; June 11, 1965.
13. Joughin, W.; EPH 7, Ephemeris of Perigee Times, Fictitious Nodes, etc.; June 1964.

DATA UTILIZATION

RESEARCH AND ANALYSIS

Satellite tracking data continue to yield significant advances in our knowledge of the upper atmosphere. From an analysis of satellite drag data gathered between sunspot maximum (1958) and minimum (1964), Dr. Luigi G. Jacchia has derived new atmospheric models based on diffusion equilibrium. With the collaboration of Dr. Max Roemer and Jack Slowey, he has computed densities of the neutral atmosphere starting from a fixed set of boundary conditions at 120 kilometers and following empirical temperature profiles defined by exponential functions of height. These models have been adopted by the U.S. Committee on the Extension of the Standard Atmosphere for inclusion in the U.S. Supplemental Atmospheres, together with the appended formulas which give the variations of temperature with solar, geomagnetic and geographic parameters.

A significant new result is the discovery that a seasonal effect exists at middle and high latitudes at all heights up to at least 600 kilometers. An analysis of observations of 14 satellites, including two 12-foot balloon satellites (1963 53A and 1964 76A) launched specifically for this research, has revealed that at any given height above 200 kilometers, the atmosphere has a maximum density in winter and a minimum in summer.

Dr. Jacchia and Mr. Slowey have also investigated the relation between exospheric temperature and geomagnetic indexes and concluded that the former varies with the solar plasma velocities in a nearly linear fashion.

Dr. Manfred Friedman has developed a set of equations to describe the structure of the upper atmosphere. The analysis based on these equations will include effects of thermal conductivity, radiative transfer and diffusion of the different constituents.

A new estimate has been made by Dr. Franco Verniani of the total mass of the earth's atmosphere. The result is $(5.136 \pm 0.007) \times 10^{21}$ grams.

Data from satellite tracking have also been used in the study of the geopotential. From precisely reduced observations of nine satellites with inclinations between 28 and 95 degrees, Dr. Yoshihide Kozai has derived new values for the coefficients of the zonal harmonics of the earth's gravitational field through J_{14}. Treating these zonal harmonics as known quantities, Imre Izsak used more than 26,000 observations of 11 satellites with inclinations between 33 and 96 degrees to compute a new set of tesseral harmonics through the sixth degree. Since independent determinations give reasonable agreement on the total contribution of the non-zonal terms to the geopotential, the main features of the geoid seem to be well established.

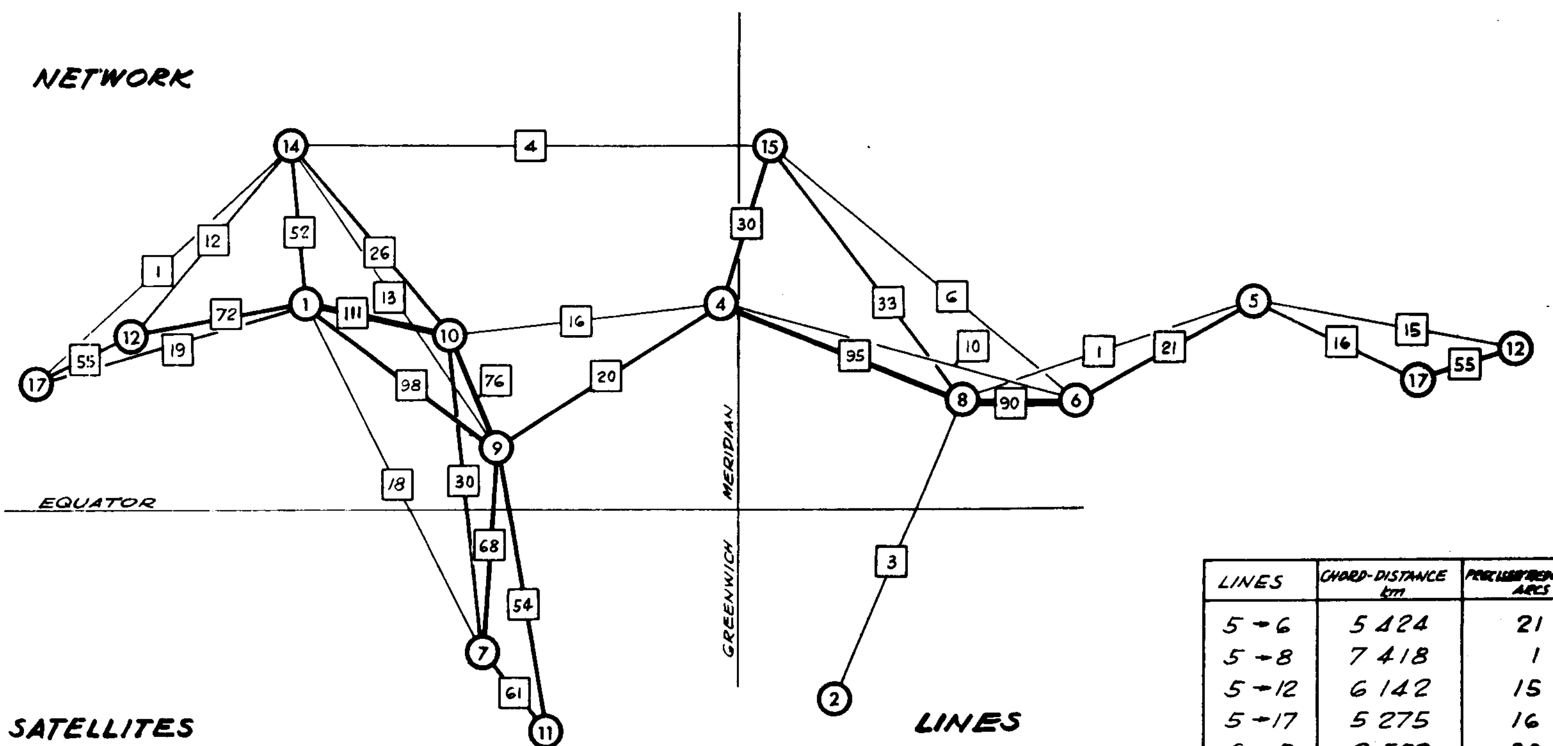
Basing his work on the results of Dr. Kozai and Mr. Izsak, E.M. Gaposchkin has improved the treatment of perturbations in the Observatory's computer program for differential orbit improvement, and is now extending the program for determining the tesseral harmonics.

The shapes for the surfaces of the constant potential and constant gravitation are being studied by Dr. Walter Köhnlein.

SIMULTANEOUS OBSERVATIONS

June 1, 1965

NETWORK



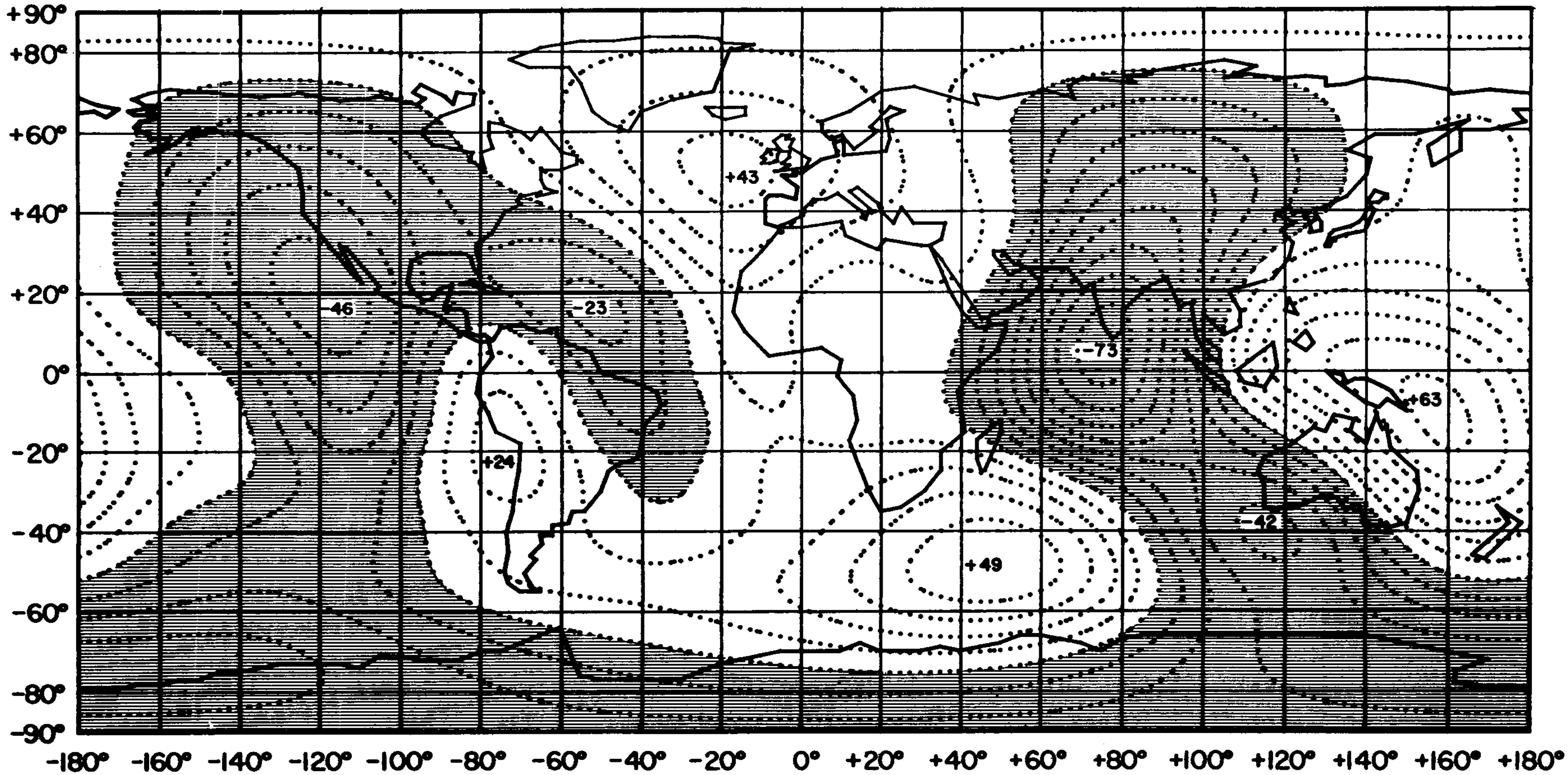
SATELLITES

NAME AND DESIGNATION		SHAPE	APPROX. ORBITAL DATA i	P min	H_P Mm	H_A Mm
VANGUARD 2	59 01 1	SPHERE	33°	130	0.56	3.30
VANGUARD 3	59 07 1	SPHERE-ROD	33°	130	0.51	3.72
ECHO 1	60 09 2	SPHERE	47°	120	1.42	1.60
EXPLORER 9	61 04 1	SPHERE	39°	120	0.63	2.50
MIDAS 4	61 28 1	CYLINDER	96°	170	3.50	3.76
TELSTAR	62 29 1	SPHERE	45°	160	0.95	5.60
ANNA	62 60 1	SPHEROID	50°	110	1.08	1.18
NONE	62 68 1	CYLINDER	82°	90	0.17	0.21
NONE	63 30 1	CYLINDER	88°	170	3.67	3.74
NONE	63 38 4	SPHERE	88°	170	3.36	4.04
EXPLORER 19	63 53 1	SPHERE	79°	120	0.60	2.37
ELECTRON 3	64 38 1		61°	170	0.40	7.03

LINES

LINES	CHORD-DISTANCE km	PRECISELY REDUCED ARCS
1 → 7	6 287	18
1 → 9	4 367	98
1 → 10	2 602	111
1 → 12	4 942	72
1 → 14	2 479	52
1 → 17	6 238	19
2 → 8	6 373	3
4 → 6	7 312	10
4 → 8	5 290	95
4 → 9	6 465	20
4 → 10	6 581	16
4 → 15	2 880	30

LINES	CHORD-DISTANCE km	PRECISELY REDUCED ARCS
5 → 6	5 424	21
5 → 8	7 418	1
5 → 12	6 142	15
5 → 17	5 275	16
6 → 8	2 589	90
6 → 15	5 831	6
7 → 9	3 139	68
7 → 10	4 780	30
7 → 11	1 826	61
8 → 15	4 499	33
9 → 10	2 021	76
9 → 11	4 769	54
9 → 14	5 725	13
10 → 14	3 859	26
12 → 14	5 238	12
12 → 17	1 461	55
14 → 15	5 985	4
14 → 17	6 271	1
	TOTAL	1126



Sixth - degree level curves of geoid heights at 10 - m intervals determined from 26,244 Baker - Nunn observations of 11.satellites.

Studies of the geophysical significance of satellite gravity results continue. From an analysis of zonal harmonics, Dr. Chi-Yuen Wang has suggested that the load of the last continental ice sheets, which persisted some 50,000 years near the end of the Pleistocene, may have deformed the earth, flattening it near the poles and causing a bulge near the equator. Since the ice sheets retreated only some 11,000 to 15,000 years ago, there has been too little time for a complete isostatic recovery of the earth, and the residual of this deformation therefore remains in the earth's ellipticity. Using different approaches, Dr. William Strange and Dr. Wang have been investigating the possible relations between heat-flow and the gravity results.

The Baker-Nunn camera system of the Observatory is a principal source of data for the NASA Geodetic Program begun this year, and studies in these fields by Observatory scientists have been and will continue to be an important part of the Program.

The rate reduction and analysis of data from simultaneous photography of satellites by two or more Baker-Nunn cameras has increased considerably during the year. From the network of 15 stations we now have data of intervisibilities that encompass the globe, providing another mathematical condition that enhances the precision of the resultant geodetic information. About 800 intervisible arcs were precisely reduced during the last year, compared to a total of 200 in the previous three years. Dr. George Veis, assisted by Leendert Aardoom and Antanas Girnius, analyzed these data to determine more precise station coordinates.

A companion program employed in the Observatory's geodetic studies determines not only the tesseral harmonic coefficients for the geopotential but also improves station coordinates from an analysis of data of orbit dynamics. Mr. Izsak determined a set of more accurate station coordinates at the same time as he solved for the tesseral harmonic coefficients.

A procedure was developed by Dr. Köhnlein to combine the results of the intervisible (geometric) method and those of the orbital (dynamic) method to determine still more accurate station coordinates and the tesseral harmonics through the fourth order. It was gratifying to learn that the geometric and dynamic methods of determining station coordinates were in good agreement. Until this comparison, it was not known whether there might be a difference in the two results due to some unrecognized factor.

EDITORIAL AND PUBLICATIONS

The Satellite Tracking Program issued the following Special Reports during this six-month period:

No. 168 -- Satellite Orbital Data by B. Miller.

No. 169 -- Catalog of Precisely Reduced Observations No. P-13 by B. Miller.

No. 170 -- Status Diffusion Models of the Upper Atmosphere with Empirical Temperature Profiles by L. G. Jacchia.

No. 171 -- Densities and Temperatures from the Atmospheric Drag of Six Artificial Satellites by L. G. Jacchia and J. Slowey.

No. 176 -- Some Results at Smithsonian Observing Stations by P. Brand, L. Solomon, J. Mazzotta, R. Proctor, J. Latimer, and E. Monash.

No. 177 -- Catalog of Satellite Observations No. C-40 by B. Miller.

No. 178 -- Catalog of Satellite Observations No. C-41 by B. Miller.

No. 179 -- Catalog of Satellite Observations No. C-42 by B. Miller.